Final Technical Report

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T-RELM: Creating a Sustainable Framework for Testing Earthquake Forecast Models

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Abstract

This grant supported the collaboration between the scientists of the USGS, SED and SCEC related to the quantitative testing of earthquake forecast models. The partners involved are jointly createing a sustainable framework for testing earthquake forecast models. The immediate objective of this project is to define community accepted procedures and software for Testing Regional Earthquake Likelihood Models (T-RELM) for California, developed as part of the RELM initiative (www.relm.org). The project objectives were fully achieved: Staring from 1/1/2007, a series of 5 years and 1 day seismicity forecast models are undergoing fully prospective testing, as documented in a special issue of SRL. The T-RELM activities have also served to initiate the Collaboratory for the Study of Earthquake Predictability (CSEP, www.cseptestin.org).

Report

Seismologists' primary societal contribution over the past 30 year has been the development of detailed seismic hazard maps, used as input for seismic engineering. Such maps portray, for example, the expected average level of shaking for a given time period, largely based on empirical observations of past seismicity and fault activity. Seismologists, however, increasingly realize that in order to significantly improve upon the current state-of-the-art in hazard assessment, a new system level, physics based and increasingly time-dependent approach to hazard assessment is needed. Starting in the year 2000, SCEC, in partnership with the USGS, initiated a new framework for the assessment of earthquake hazard in Southern California: The *Regional Earthquake Likelihood Initiative* (RELM, www.relm.org). RELM involves a multitude of Earth scientists from different disciplines, all developing earthquake-rupture forecast (ERF) for SC at various time- and space-scales. A total 19 models have been developed and implemented, including seismicity-based short-term forecasts, geodetically drive models, pattern recognition algorithms, stress interaction and rate-and-state models and purely numerical models. See [*Field*, 2007] and the special volume of Seismological Research Letters (Feb. 2007) for more details on the RELM project

An example of the kinds of models that are being developed is shown in Figure 1. Shown is the Short Term Earthquake Probabilities (STEP; [*Gerstenberger et al.*, 2005; *Gerstenberger et al.*, 2007] model, which predicts the probability of strong ground shaking in the next 24-hour periods, based on simple statistical models of the observed clustered seismicity of the seismicity until then. These forecasts, updated hourly, are available on the USGS web site *step.caltech.edu* starting March 2005; a snapshot of this page on January 21 is shown in Figure 1. In many locations, the time-dependent contribution to earthquake hazard exceeds the stationary background 10 – 1000 fold. Surprisingly, these effects are long lasting; hazard 'echoes' of large events remain significant contributors even years, sometimes decades, after the respective mainshock. Purely statistical models such as STEP or related Epidemic Type Aftershock model (ETAS [*Helmstetter and Sornette*, 2002; *Ogata*, 1999]), offer a much needed Null hypothesis against which more sophisticated, physics-based forecast models can be tested against. An example of a long-term(5-year) model created within RELM is shown in Figure 2, the ALM model [*Wiemer and Schorlemmer*, 2007].

Uniquely in seismology, all RELM modelers have recently agreed upon a community spirit testing of their forecast models in a fully prospective sense. In the past, it has been impossible to quantitatively compare performance of various models, because forecast regions, forecast periods, magnitude ranges and, most importantly, forecast scoring approaches varied widely. By creating a framework for *T*esting *R*egional *E*arthquake *L*ikelihood *M*odels (T-RELM), a partnership of scientists from SCEC, the USGS and the Swiss Seismological Service (SED) have created a new rigorous testing standard that will greatly advance forecasting related research in seismology. The funding from this NEHRP grant, supported by SED and SCEC internal resources, has made the implementation of T-RELM possible,

The community based likelihood model testing and 'rules of the game' developed within RELM and T-RELM encompass the following key concepts ([*Schorlemmer and Gerstenberger*, 2007; *Schorlemmer*, 2007]);

- Forecasts are issued for two sets of contests. A) Strongly time-dependent models, forecasting the seismicity of the next 24-hour period, based on observations until midnight. Examples of such models are an Epidemic Type Aftershock Model (ETAS, [*Helmstetter and Sornette*, 2002; *Ogata*, 1999] or STEP; B) Quasi-stationary models. These models forecast seismicity for a five-year period, and are evaluated yearly.
- Each model forecasts the seismicity in 5 x 5 km bins for a predefined region covering California. Forecasted are occurrence rates in each magnitude bin, spaced 0.1 units apart, spanning the magnitude range 4 – 9 (contest A) and 5 – 9 (contest B).
- Forecasted rates are assumed poissonian, and compared to the actually observed rates in each space-time-magnitude bin. The performance of each model is measured relative to all other models in the same contest using a likelihood ratio test. Simulating 1000 realizations of each model, establishes the significance of likelihood ratio differences. The 'winning' model of each contest is the one that beats most others in direct comparison, and is consistent in the forecasted number and likelihood with the observations.

- Each model in contest A is implemented on a central testing computer; modelers must deposit their code and have no access to it, in order to ensure truly perspective testing. The code has access to authorized data sources only, such as the CISN network catalog, and testing is performed in a time-lagged fashion, in order to allow testing against quality controlled data.

The RELM group, supported in parts by this grant, developed a suite of likelihood tests [*Schorlemmer*, 2007] to be implemented within a Testing Center, a facility in which earthquake forecast models are installed as software codes and in which all necessary tests are conducted in an automated and fully prospective fashion [*Schorlemmer*, 2007]. 19 earthquake forecasts were submitted for prospective testing in the period of 1 January 2006, 00:00–1 January 2011, 00:00. These forecasts were not installed as software codes in the Testing Center because the RELM group decided to use simple forecast tables; nevertheless, the processing is fully automated and does not require human interaction. Figure 3 and 4 illustrate the temporal delay in testing and the testing and collection region, respectively.

The T-REM activities thus successfully implemented the first fully prospective, real-time test of a variety of earthquake forecast models using community accepted testing standards. We consider this a major milestone in advancing research on earthquake hazard and forecasting. In addition, the T-RELM funding formed the foundation for the much larger, international Collaboratory for the study of earthquake predictability (CSEP, www.cseptesting.org), funded by the Keck foundation, SCEC and international partner projects such as the EU FP6 program NERIES (www.neries-eu.org/). Without the intermediate T-RELM step, CSEP may not have happened. CSEP is now also continuing the testing of the RELM models; results of the model comparison can be viewed online at www.cseptesting.org/centers/scec/. The end of the 5-year testing period on Dec. 31 2010 marks another important milestone; it will allow to evaluate the performance of the models after a sufficient period to allow for meaningful statistical analysis.

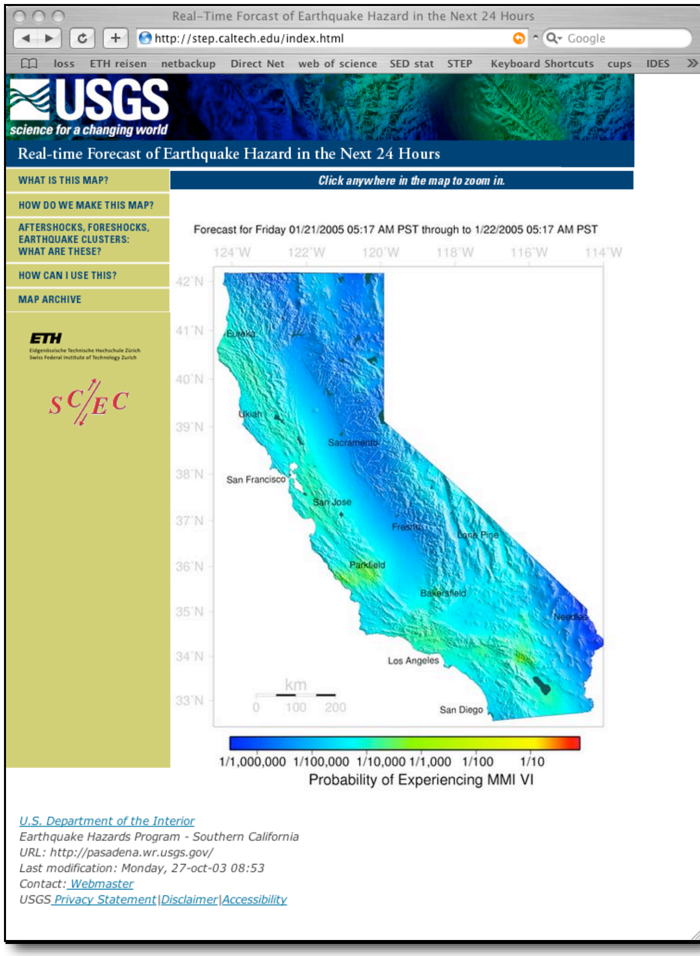

Figure 1: Snapshot of the STEP model, a one-day forecast model and one of the models tested in real-time in the T-RELM framework supported by this grant. See Gerstenberger et al. (2005), for more information.

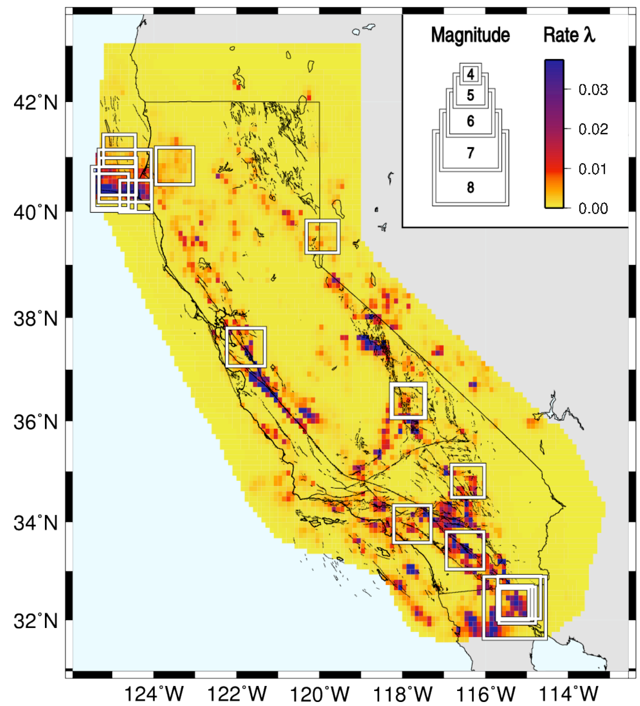

Figure 2: Snapshot of the STEP model, a 5-year forecast model and one of the models tested in real-time in the T-RELM framework supported by this grant. See Wiemer and Schorlemmer (2007) for more information.

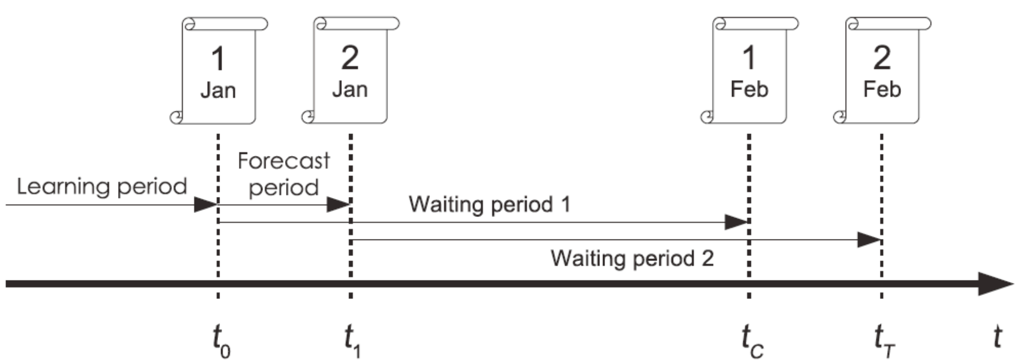

Figure 3. Time line of forecasting and testing agreed in the T-REM experiment (from Schorlemmer and Gerstenberger, 2007). Any model generates its forecast at t_0 using all data from the learning period. The forecast is valid for the period from t_0 to t_1. The revised catalog for forecast generation is available after the waiting period 1 at t_C. Testing can be performed after the waiting period 2 at t_T.

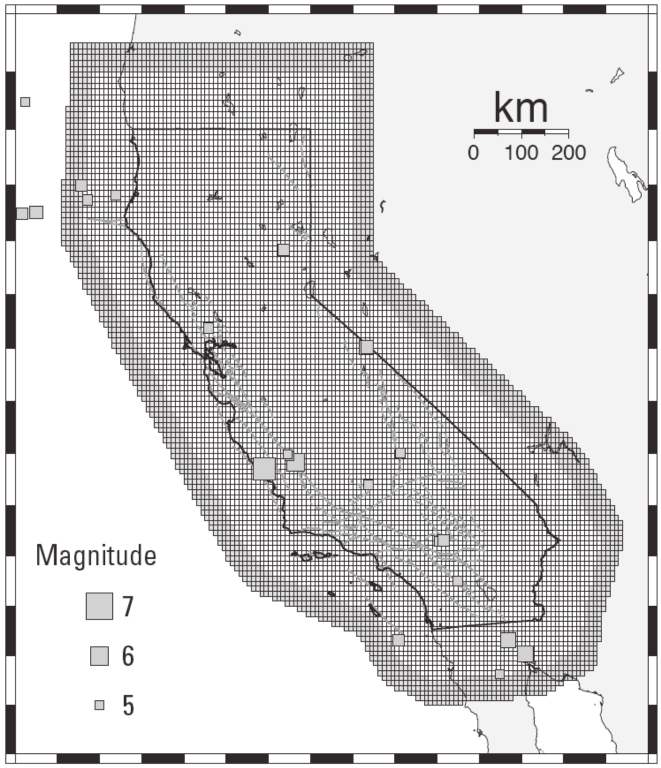

Figure 4. Testing and collection area (from (from Schorlemmer and Gerstenberger, 2007). The white squares indicate spatial cells of the testing area. The cells extending the testing area to the collection area are drawn in gray. Main faults are indicated with gray lines. The squares mark earthquakes of magnitude **M** ≥ 5 of the ANSS catalog in the period 2000–2005.

References

Reference in bold are immediate project results.

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